Sustainable Pavement Rehabilitation: Thin Bonded Wear Course with High Taconite and Recycled Asphalt Shingles Mix

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February 14th 2013

17th Annual TERRA Pavement Conference

St. Paul, MN

Outline

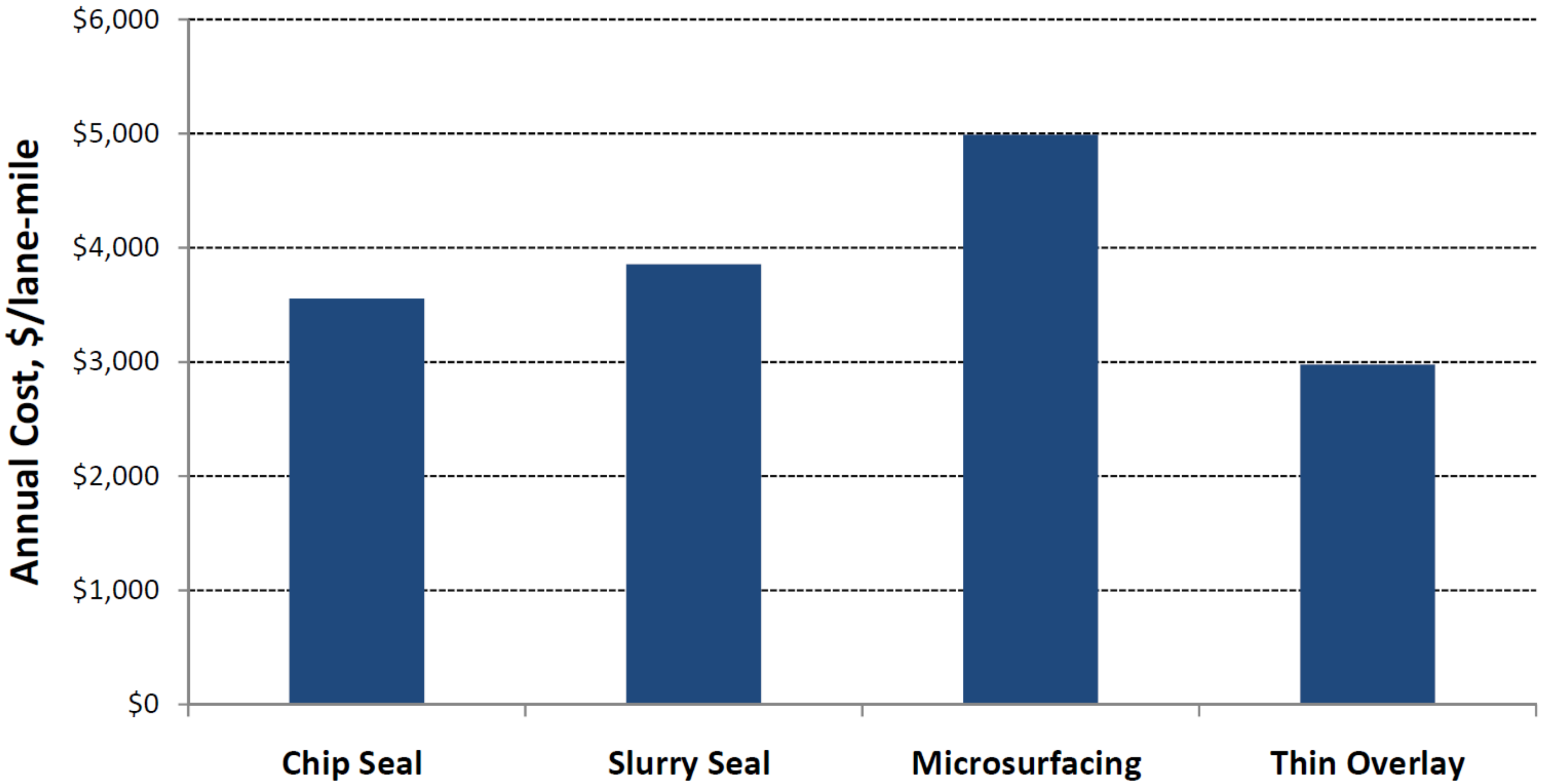
- Thin Bonded Overlays / Wearing Courses
- Yosemite Avenue Project
- Sustainability Evaluation of the Project
- Laboratory Characterization of Field Samples
- Summary

Thin Asphalt Overlays/Wear Courses

- Historically thin asphalt overlays were treated as means of pavement preservation
  - Current usage is more driven by pavement rehabilitation
    - *Capping mixes on reclaimed and recycled (FDR, CIR, FIR) layers*
    - *Surface improvement overlays*
    - *Mill and fill*
- Thin overlays / wear courses can have significant pavement rehabilitation benefits
  - Sealing pavement surface
  - Skid resistance and smoothness
  - Improved thermal cracking performance
  - Maintain clearance and profiles
  - Ability to recycle
  - Noise benefits
  - Life cycle extension
  - Construction and material quality

Thin Asphalt Overlay – Cost Effectiveness

- Life Cycle Cost Analysis
  - Wolters and Thomas, 2010



Thin Asphalt Overlays / Wear Courses

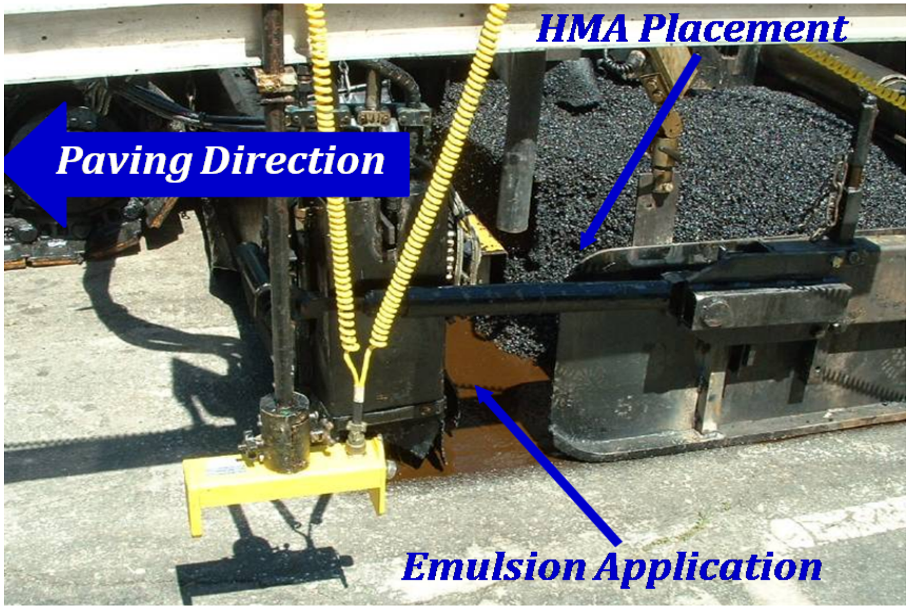
- Typical thicknesses: < 1.5 inch
  – Ultra Thin < 1 inch

- Requires some mix design innovations
  – Use of performance tests
  – Number of provisional specifications

- Different placement approaches
  – Traditional HMA placement
  – Thin bonded asphalt course Placed using Spray-paver

Thin Bonded Asphalt Wear Course Construction

- Single Pass Paving Process: Spray Paver
- Range of HMA types
- High application rate of uniform Tack Coat
  (3-5 times > conventional)



- Benefits
  - No Tack Coat Tracking
  - Improved Bonding
  - Provides Waterproofing
  - Rapid Construction (30 to 120 ft/min)

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City of Duluth Field Study

- Project: Yosemite Avenue (N-W Duluth)
  - Low volume residential street
- Typical City Rehabilitation
  - Mill existing asphalt
  - Regrade (and reclaim) base
  - Wear Course: 1.5 inch
  - Non-Wear (Binder) Course: 2 inch
- Three 1000 ft. test sections
  - Section-1: Traditional Approach (Control section)
  - Section-2: 1 inch thin bonded wear course
  - Section-3: ¾ inch thin bonded wear course

Yosemite Avenue

- Prior to Rehabilitation

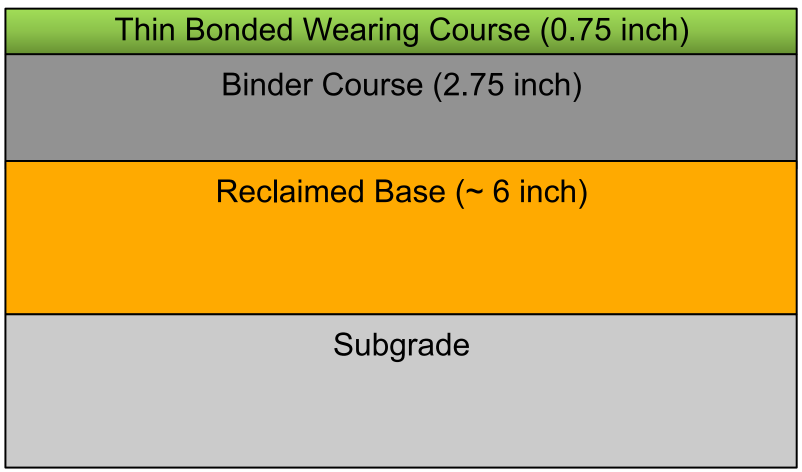
Design Philosophy

- Design Needs:
  - High Friction Surface (Ice and Snow)
  - High Cracking Resistance
    - *Prevent low temperature cracking*
  - Moderate load carrying capacity
    - *Garbage trucks, occasional delivery trucks etc.*
  - Smooth Surface (Bike friendly)
- Approach
  - Thin bonded wear course on surface (High performance sustainable mix)
    - *Provide high toughness (crack resistant) layer*
    - *Excellent water proofing*
    - *High friction*
  - Non-wear courses
    - *2.5 – 3 inch regular hot-mix*
    - *High stiffness and load carrying capacity*

Section-1 (Control)

Section-2

Section-3



Section-2:
- Thin Bonded Wearing Course
- Engineered Emulsion Tack Coat – 0.08 gal/sq. yd.

Section-3
- Thin Bonded Wearing Course
- Engineered Emulsion Tack Coat – 0.20 gal/sq. yd.

Materials in Thin Wear Course Mix

- Taconite Tailings:
  - By-product from taconite mining operations at Minnesota Mesabi Iron Range (MMIR)
  - Annual production = 125 Million Tons
    - *Most of this ends up in land-fills around mines*
  - MnDOT and UMD-NRRI have conducted significant feasibility research on use of tailings in HMA

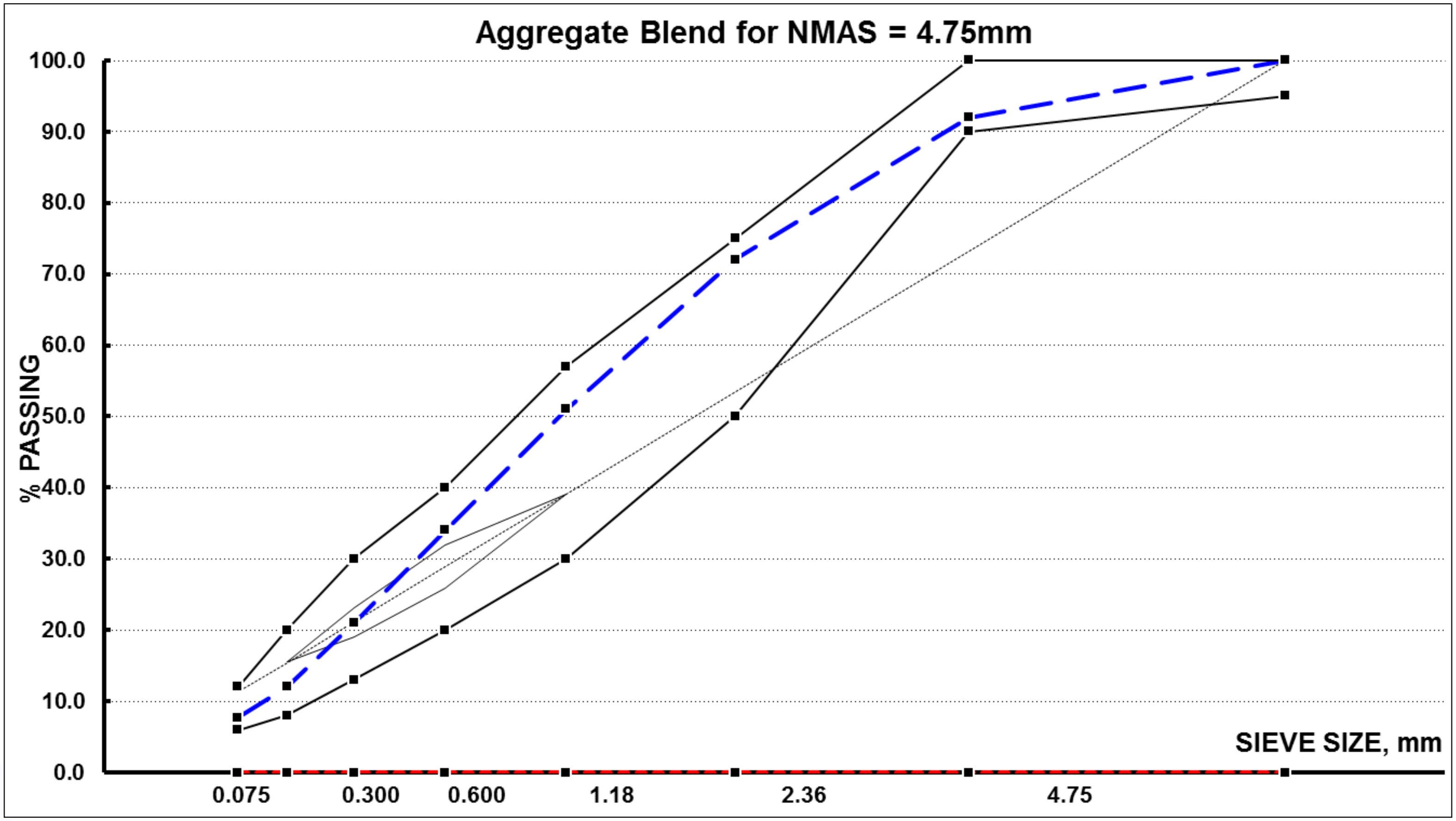
- Recycled Asphalt Shingles
  - Rich in Asphalt Binder (18-40%)
  - Annual Availability = 10 Million Tons

Mix Design for Yosemite Avenue

- Number of recent studies have proposed various volumetric limits for 4.75 mm mixes (more research is underway)
- Started with six aggregate blends that met the AASHTO specifications for gradation
  - Bailey method approach was utilized to optimize the aggregate packing
- Focused on VMA and VFA at 4% Air void level
  - Reduced to three gradations for asphalt content trails
- The design with highest taconite tailings content (45.5%), 5% recycled shingles and VMA above 16.0% was chosen

Thin Overlay Mix Design – Yosemite Avenue

Aggregate Percentages					Design Asphalt Content (%)
Taconite Tailing	BA Sand	Crusher Fines	Dust	RAS	
45.5	24.5	29.0	1.0	5.0	7.7



Yosemite Avenue: Control and Non Wear Course

Constructed in August 2011

MnDOT 2360 Mix
30% RAP

Yosemite Avenue: Bonded Wear Course

Paving Date: 9/19/2012
Hail in afternoon and rain during paving
Spray paver construction

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Pavement Sustainability Rating Systems

Rating System Attributes	Sustainable Rating Systems				
	PaLATE	Greenroads	GreenLITES	INVEST	I-LAST
Based on Point System (Qualitative Approach)	-	ü		ü	ü
Accounts for: Environmental Effects, Materials, Energy, and Sustainable Practices	ü	ü	ü	ü	ü
Quantitative Input: Roadway Design, Construction, Maintenance, and Cost	ü	-	-	-	-

PaLATE Results

- Focus on energy demands and CO_2 emissions:
  - Material Production
  - Transportation and Construction
- Comparison between traditional asphalt mix (with 30% RAP) and the Taconite-RAS mix

Energy Demand (MJ / inch-mile placed)

Mix Type	Mat. Prod.	Transp. & Const.	Total
Traditional Mix	744,577	20,598	765,175
Taconite+RAS Mix	599,820	$\boxed{34,608}$	634,428

CO_2 Emissions (kg/ inch-mile placed)

Mix Type	Mat. Prod.	Transp. & Const.	Total
Traditional Mix	32,373	1,540	33,913
Taconite+RAS Mix	30,230	$\boxed{2,587}$	32,817

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Lab Testing of Field Samples

- Mix Volumetrics
  - Loose Mix and cored samples were collected and tested by Golder Associates
  - Marshall flow and stability tests were also conducted by Golder Associates
- Portable Bond Test
  - Evaluation of bond between wear course and underlying layers
  - Cored samples were provided to Road Science for testing using the Portable Bond Tester (PBT)
- Disk Shaped Compact Tension (DCT) Fracture Energy Test
  - Provides measure of the cracking resistance of the mix
  - Has been shown to correlate very well against low temperature cracking amount

Mix Volumetrics

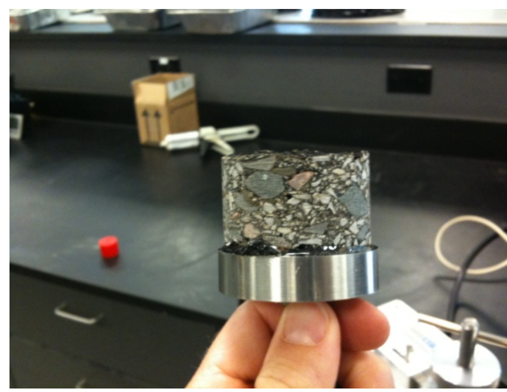
- Air Void Level (Core samples) = 4.3%
- Nuclear Gage = 8 – 13%
  - Very thin lift, gage not calibrated to this type of mix
- Total Asphalt Content = 7.9% (with tack coat)
  - Plant Mix = 7.7%

- Voids in Mineral Aggregate (VMA) = 19.3%
- Voids Filled with Asphalt (VFA) = 77.7%
- Percent crushed = 95%

- Marshall Stability = 11,972 N (2,690 lb.)
  - Usually required limit for heavy traffic is 8,000 N
- Marshall Flow = 11.6 (0.25 mm / 0.001 inch)
  - For heavy traffic: 8 - 14

Portable Bond Test Equipment

- Equipment and test under evaluation
- Use in lab or in field
- Portable, battery powered, weight ~25#
- Data acquisition, captures load and travel
- 0.5 mm/min rate of travel
- 2 inch diameter specimens on road or in larger core
- 500 lb. load capacity



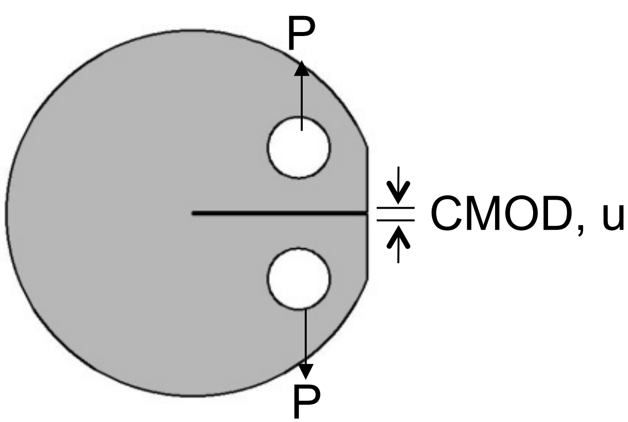
Portable Bond Tester Results

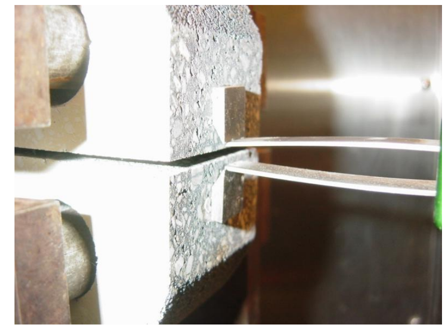
Section	Time (Days after construction)	Bond Energy J/m^2
2 (0.08 gal/yd^2)	42	24.8
	57	45.2
3 (0.20 gal/yd^2)	37	33.6
	42	42.5
	57	39.0

- All cores were obtained within 2 days of paving
- Testing of additional cores is planned

Disk-Shaped Compact Tension (DCT) Test

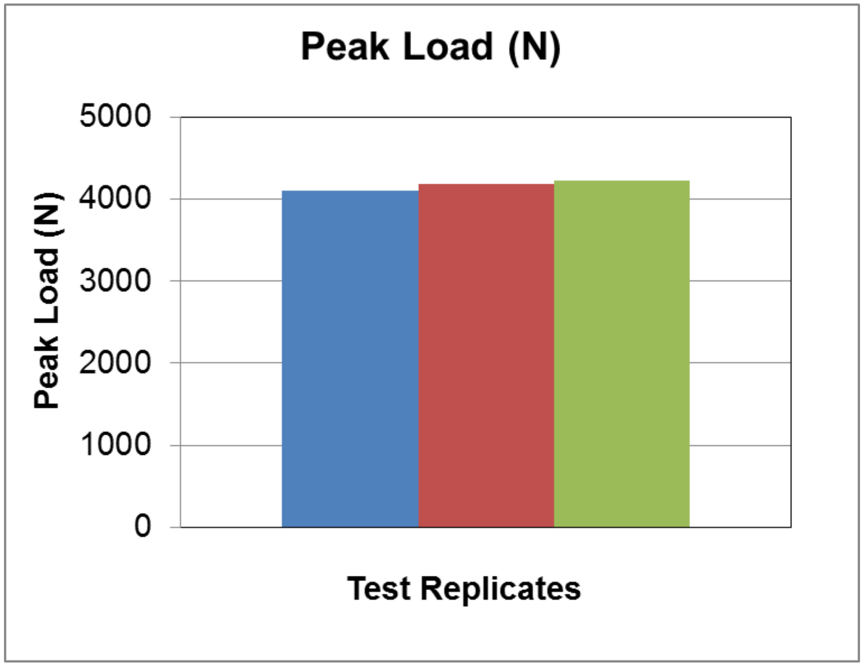
- ASTM D7313
- Loading Rate:
  - Crack Mouth Opening Displacement
  - CMOD = 1.0-mm/min
- Measurements:
  - CMOD
  - Load





ASTM D7313: Standard Test Method for Determining Fracture Energy of Asphalt-Aggregate Mixtures Using the Disk-Shaped Compact Tension Geometry

Fracture Energy Results for the Taconite-RAS Mix



Test Temperature = -24ºC
Recommended Minimum = 400 J/m^2

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Summary

- The current mill and fill approach used for rehabilitation of low volume roads can be improved to extend the maintenance dollars
- Use of thin bonded wear course provides good opportunity to improve the performance of roadways:
  - Good friction
  - Waterproofing
  - Cracking resistance
- Combining thin bonded wear course with high taconite and RAS mix can yield sustainable results:
  - Lower material costs and environmental impacts (Tailings and RAS)
  - Reduced thicknesses of underlying non-wear courses
  - Average cost difference between control section and the thin bonded wear course section ~ 9%

Summary (cont.)

- Few cracks in all test sections due to base settlement
  – No thermal cracks so far
- Longitudinal joint on control section is cracking

Thank you for your attention!!!

Questions?

Acknowledgements:

- City of Duluth
- LRRB Local Operational Research Assistance (OPERA) Program
- Minnesota Department of Transportation
- Road Science
- UMD Natural Resources Research Institute (NRRI)
- Golder Associates

Thin Overlay – Asphalt Mix Considerations

- Open/gap graded and SMA mixes
  - Requires high quality aggregate
  - High air void content
  - Good friction and drainability

- Dense graded mixes
  - Significant effort on development of gradation and volumetric criteria for 4.75 mm mixes
  - High surface smoothness
  - Good pavement sealing and may add surface cracking benefits

Thin Overlay – 4.75 mm Mix Designs

- Significant research has been undertaken in recent years
- James et al. (2007)
  - Proposed gradation and volumetric requirements

Gradation Control

- *9.5 mm 95 – 100%*
- *4.75 mm 90 – 100%*
- *1.18 mm 30 – 54%*
- *0.075 mm 6 – 12%*

Volumetrics

- ***Min. 16% VMA***
- ***VFA: 75 – 78% (high traffic), 75 – 80% (low traffic)***
- ***Dust proportion 0.9 – 2.2***

Thin Overlays: 4.75 mm Mix Design

- AASHTO M 323 Specifications:

Design ESALs (Millions)	N_{des}	FAA Depth from Surface ≤ 100 mm	FAA Depth from Surface ≥ 100 mm	SE	VMA	VFA	N_{ini}
<0.3	50	-	-	40	16.0	70-80%	≤91.5
0.3 to <3.0	75	40	40	40	16.0	65-78%	≤90.5
3.0 to<10	75	45	40	45	16.0	75-78%	≤89.0

Sieve size	Min.	Max.	V_a = 4.0%
12.5 mm	100		D:B Ratio: 0.9 to 2.0
9.5 mm	95	100	
4.75 mm	90	100	
1.18 mm	30	60	
0.075 mm	6	12	

Thin Overlays - 4.75 mm Mix Design

- NCAT Study (West et al., 2011)
  - Major modification from AASHTO specification: Use of V_{be} instead of VMA and VFA
  - This modification is based on performance tests

Design ESAL Range (Millions)	N_{des}	Minimum FAA	Minimum SE	Minimum V_{be}	Maximum V_{be}	$\%G_{mm}@N_{ini}$	D:B Ratio
<0.3	50	40	40	12.0	15.0	≤91.5	1.0 to 2.0
0.3 to ≤ 3.0	75	45	40	11.5	13.5	≤90.5	1.0 to 2.0
3.0 to ≤ 30	100	45	45	11.5	13.5	≤89.0	1.0 to 2.0
Gradation Limits							
Sieve Size	Max.	Min.		Design V_a Range = 4.0% to 6.0%			
12.5 mm	---	100					
9.5 mm	100	95					
4.75 mm	100	90					
1.18 mm	30	55					
0.075 mm	13	6					

Effective binder amount

Thin Overlays – 4.75 mm Mix Designs

- Texas (Scullion et al., 2009): CAM

Sieve Size	Fine Mixture (% Passing by Weight or Volume)
1/2"	–
3/8"	98.0–100.0
#4	70.0-90.0
#8	40.0–65.0
#16	20.0-45.0
#30	10.0–30.0
#50	10.0–20.0
#200	2.0–10.0

- 2 – 4% Air Voids
- Design is based on performance tests
  - Hamburg and Texas Overlay Tester

Thin Asphalt Overlays: MnROAD

- Two test sections in Cell-6
- Mix consists of significant quantities of Taconite tailings

Mix Type	Proposed AASHTO Criteria	MnDOT SPWEB440F Special
Mix Size	4.75 mm NMAS	4.75 mm NMAS
Binder Type		PG 64 -34 (polymer modified)
Binder Content		7.4%, Pbe=6.9
Aggregate Blend		55% Taconite tailings (Mintac) 10% Taconite tailings (Ispat) 35% Man-sand (Loken)
Target Gradation	30%–55% passing 1.18 mm Sieve 6-13% passing 0.075 mm Sieve	51% passing 1.18 mm Sieve 7.7% passing 0.075 mm Sieve
Aggregate Properties	FAA = 45 (min) SE = 45 (min) Nat.Sand=15(max) if FAA<45	FAA = 47 SE = 83 N/A
Air Voids	4.0%–6.0% (N_{des}=75 gyrations) 89.0 max (%G_{mm} @ N_{ini})	V_a=3.9% at N_{des} =75 gyrations Not reported
Volumetric Properties	V_{be} 11.5-13.5 VMA 16.0 min. (note 1) VFA 65-78 (note 1) D:B ratio 1.5-2.0	V_{be}=16.4 VMA=20.3 VFA 80.8 D:B ratio =1.1
Moisture Susceptibility		TSR=0.82 @ V_a = 9.0%